1. Introduction

Managing the increasing volume of air traffic requires not only an incremental upgrade of present systems, but an entirely new paradigm for the complete air traffic management (ATM) system/communication, navigation and surveillance (CNS) systems. The next-generation CNS/ATM system must control aviation both flexibly and safely. In the future, an aircraft should be able to select its course more freely than at present, and also the flow of air traffic should be more efficient. Aircraft should be able to approach and land safely even under severe weather conditions. The new system should also be harmless to the environment.

To achieve these aims, the next-generation navigation system should include the following features. 1) Accuracy to meet global standards as required in each phase of flight. 2) Fault detection to ensure system integrity. 3) Simple, low-cost equipment.

We propose MSAS-GAIA as a next-generation navigation system that meets these challenges, reliably providing excellent navigational performance without complex systems.

2. Concept of MSAS-GAIA

Fig. 1 shows the flight phases for which conventional navigation systems (VOR/DME, ILS, radio and barometric altimeters) and the proposed system MSAS-GAIA provide the required navigational performance (RNP). No conventional system can do the job on its own through all flight phases, but MSAS-GAIA is usable at any time as a stand-alone system. GAIA is a GPS-aided inertial navigation system that was originally developed for the automatic take-off and landing mission of the HSFD (High Speed Flight Demonstrator). It uses GBAS (Ground Based Augmentation System) to achieve CAT-III navigation performance. MSAS (MTSAT Satellite Based Augmentation System) is the proper name of the SBAS (Satellite Based Augmentation System), developed by the Ministry of Land, Infrastructure and Transportation to provide SBAS information in the Japan FIR (Flight Information Region). We added SBAS information to the original GAIA, which can now automatically switch the supplementary information source from GBAS to SBAS according to the flight phase, as shown in Fig. 1. Fig. 2 shows MSAS-GAIA; only the onboard software is modified from the original to enable decoding the SBAS message.

3. Flight evaluation of MSAS-GAIA

The purposes of the flight evaluation are 1) to confirm the performance of the SBAS augmentation of the original GAIA with respect to both accuracy and continuity and 2) to demonstrate seamless switching between SBAS and GBAS.

To perform the flight experiment we installed...
MSAS-GAIA on the test aircraft, Dornier 228. Besides the GBAS message, the onboard receiver also gets the SBAS information from Kobe MCS (Master Control Station) via ISDN because MT-SAT has not yet been launched. MSAS-GAIA autonomously selects the appropriate decoding routine by examining the data encoded on the carrier.

Fig. 3 summarizes MSAS-GAIA navigation performance with SBAS augmentation. In this figure, we show the 95% confidence limits of navigation system error (NSE) in the horizontal direction with the symbol □ and in the vertical with a ▼. Maximum and minimum values of vertical protection level (VPL) and horizontal protection level (HPL) are plotted for all experiments. The protection level indicates the limit of the navigation error, analytically estimated with a probability of $2 \times 10^{-9}$ horizontally and $1 \times 10^{-7}$ vertically. When HPL and VPL are less than the alert limit and NSE also meets requirements, MSAS-GAIA is considered available. The symbol ▼ shows the availability of MSAS-GAIA for APV-I. We have used conservative assumptions for maximum safety when calculating the PL value. Thus the continuity is not sufficient for APV-I and the availability is relatively low. However, the availability for Enroute/Terminal and Non precision approach was 100% in all experiments.

Fig. 4 shows SBAS/GBAS switching. When we switched the supplementary information from SBAS to GBAS, MSAS-GAIA successfully changed the decoding routine, and within 10 sec after the switch, the height error converged to less than 1 m and VPL was around 3 m, which meets CAT-III requirements.

4. Conclusions

We proposed and evaluated the MSAS-GAIA concept, and flight-tested it. The experimental results for NSE (mean value for the total flights is 6.01 m horizontally and 7.37 m vertical) and availability (100% for Enroute/Terminal and Non precision approach) show the benefit from SBAS augmentation. The SBAS/GBAS switching was performed successfully, and seamless navigational performance by MSAS-GAIA was confirmed for all flight phases.